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LAND USE CHANGE AND NITROGEN ENRICHMENT OF A ROCKY MOUNTAIN WATERSHED

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Abstract. Headwater ecosystems may have a limited threshold for retaining and removing nutrients delivered by certain types of land use. Nitrogen enrichment was studied in a Rocky Mountain watershed undergoing rapid expansion of population and residential development. Study sites were located along a 30-km transect from the headwaters of the Blue River to Lake Dillon, a major source of drinking water for Denver, Colorado. Ground water in residential areas with septic systems showed high concentrations of nitrate-N (4.96 ± 1.22 mg/L, mean ± SE), and approximately 40% of wells contained nitrate with $\delta^{15}N$ values in the range of wastewater. Concentrations of dissolved inorganic nitrogen (DIN) in tributaries with residential development peaked during spring snowmelt as concentrations of DIN declined to below detection limits in undeveloped tributaries. Annual export of dissolved organic nitrogen (DON) was considerably lower in residential streams, suggesting a change in forms of N with development. The seasonal $\delta^{15}N$ of algae in residential streams was intermediate between baseline values from undeveloped streams and stream algae grown on wastewater. Between 19% and 23% of the annual N export from developed tributaries was derived from septic systems, as estimated from the $\delta^{15}N$ of algae. This range was similar to the amount of N export above background determined independently from mass-balance estimates. From a watershed perspective, total loading of N to the Blue River catchment from septic and municipal wastewater (2 $kg \cdot ha^{-1} \cdot yr^{-1}$) is currently less than the amount from background atmospheric sources (3 $kg \cdot ha^{-1} \cdot yr^{-1}$). Nonetheless, nitrate-N concentrations exceeded limits for safe drinking water in some groundwater wells (10 mg/L), residential streams showed elevated seasonal patterns of nitrate-N concentration and ratios of DIN to total dissolved phosphorus, and seasonal minimum concentrations of nitrate-N in Lake Dillon have increased exponentially to 80 μg/L over the last decade from an initial value near zero. Results suggest that isotopic ratios in autotrophs can be used to detect and quantify increases in N enrichment associated with land use change. The biotic capacity of headwater ecosystems to assimilate increases in inorganic N from residential development may be insufficient to prevent nitrogen enrichment over considerable distances and multiple aquatic ecosystems downstream.

Key words: *algae; land use; N enrichment; N isotopes; nitrate; streams; wastewater.*

INTRODUCTION

Changes in land use are occurring at an accelerated rate throughout many regions of North America, including headwater ecosystems, which contain some of the fastest growing populations within the United States. Watersheds in these areas often contain critical habitat for biota and are used by humans for recreation and as supplies of drinking water (Jackson et al. 2001, Messerli 2004). The balance between these demands is sometimes controversial and can be of great environmental and economic consequence (e.g., Lewis et al. 1984, Byron and Goldman 1989, Daily and Ellison 2001, Korner 2004).

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Because of concerns regarding deterioration of habitat and ecosystem services, much work has examined the effects of nutrient enrichment from atmospheric deposition on headwater areas (Lewis et al. 1984, Baron et al. 1994, Sickman et al. 2003, Likens 2004). The effects of atmospheric N pollution originating from power plants, vehicles, and agricultural and urban sources include stimulation of primary production (Wolfe et al. 2002), alteration of biotic communities (Baron et al. 2000, Wolfe et al. 2001), reduced quality of drinking water (Williams et al. 1996, Williams and Tonnesson 2000), and propagation of increased amounts of inorganic N through aquatic ecosystems (Baron et al. 1994, Williams et al. 1996).

Although less recognized, rapid increases in tourism and residential and suburban development of headwater areas may also lead to considerable nutrient enrichment in the eastern and western United States (Lewis et al. 1984, Byron and Goldman 1989, Daily and Ellison 2001). There can be substantial processing of inorganic